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PELLETIZED ASPHALT FOR AIRFIELD DAMAGE REPAIR

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14. ABSTRACT
The use of pelletized asphalt technology to produce airfield-quality hot-mix asphalt (HMA) is evaluated in this study. The pelletization process produces HMA mix components (asphalt cement, fine aggregate, fiber, and polymer) as a pre-manufactured product that could be shipped at ambient temperature to a remote location. There, it can be introduced to locally-produced, heated coarse aggregate in a continuous or batch plant. Two HMA mix types known to provide high shear and rutting resistance were designed and subjected to laboratory tests; one was the stone mastic asphalt (SMA) mix, and the other was a dense-graded airfield (DGA) HMA mix. Laboratory tests using the asphalt pavement analyzer indicated that DGA mixes had better rutting resistance compared to the SMA mixes. Thus, the test sections (one pelletized mix and one conventional HMA mix) at Silver Flag Test Area were built using the DGA mix gradation; the conventional HMA mix served as the experiment control. The test sections were trafficked with 1,500 passes of the F-15E load cart to evaluate the rutting performance of the pelletized asphalt HMA. The pelletized asphalt HMA section showed no rutting; the conventional asphalt experiment control test section exhibited as much as 22 mm of rutting. The study concluded that it is feasible to produce airfield-quality HMA with pelletized asphalt using conventional HMA plants. Conventional equipment was adequate for placing a durable and rut-resistant pelletized HMA. This paper presents results of laboratory and field tests and provides status of field implementation of the technology.

15. SUBJECT TERMS
Hot mix asphalt, HMA, asphalt pavement, pelletized asphalt, stone matrix asphalt, SMA, dense graded asphalt, DGA, permanent deformation, rutting, deployable asphalt plant, load cart testing

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1. SUMMARY

This study evaluated the use of asphalt binder pelletization technology to produce airfield-quality hot-mix asphalt (HMA) for contingency and expedited airfield repairs. The pelletization process produces HMA mix components (asphalt cement, fine aggregate, fiber, and polymer) as a pre-manufactured product that could be shipped at ambient temperature to remote locations. Two candidate HMA mixes were designed for optimal asphalt content and voids content and assessed using laboratory and field tests were used to determine the performance of pelletized asphalt. Laboratory tests for workability and rutting potential helped select one of the HMA mixes for full-scale accelerated field trials.

Based on laboratory performance tests, a dense-graded asphalt (DGA) mixture was selected for field evaluation. Field experiments evaluated production and placement of pelletized asphalt HMA using a standard asphalt plant and equipment as well as performance under simulated aircraft load. Two test sections were built on an existing Portland cement concrete (PCC) runway at the Silver Flag Training Area at Tyndall Air Force Base (AFB), Florida. One section of the HMA used conventional asphalt binder and the second section used pelletized asphalt binder. During construction, conventional HMA production plant and placement equipment was found adequate for construction of HMA produced using pelletized asphalt binder.

The pelletized asphalt binder test section exhibited no permanent deformation; conventional asphalt binder test section showed considerable deformation. The maximum deformation observed in conventional asphalt after 1504 passes was 22.5 mm, 2.5 mm short of the defined failure criteria.

The study concluded that it is feasible to produce airfield-quality HMA with pelletized asphalt binder using conventional HMA production plant. Also, conventional equipment is adequate for performing pelletized HMA repairs of damaged airfields. Furthermore, the laboratory and field experiments indicated that the HMA mix with pelletized asphalt binder performed better than HMA mixes with conventional asphalt binder.

2. INTRODUCTION

2.1. Background

Asphalt pelletization technology provides a promising way to accomplish airfield pavement repairs expeditiously in locations where producing airfield-quality hot-mix asphalt (HMA) mixes are difficult. The pelletization process produces HMA mix components (asphalt cement, fine aggregate, fiber, and polymer) as a pre-manufactured product that could be shipped at ambient temperature to a remote location. There, it can be introduced to locally-produced, heated coarse aggregate in a continuous or batch HMA mix plant.

The Office of the Secretary of Defense and Air Combat Command provided financial support for the Air Force Research Laboratory (AFRL) to develop the technology to use pelletized HMA for expedient and contingency airfield damage repairs (ADR). The asphalt pellets and the related production technology developed and patented by the New Innovative Technologies (NiTech) Corporation represents a key technology in developing new ADR procedures and a success for AFRL's mission of leading science and technology.

2.2. Objective

The objective of this research effort was to develop and evaluate an HMA mix designed using pelletized asphalt that is workable during construction and performs satisfactorily when subjected to mixed aircraft traffic. Stone mastic asphalt (SMA) mix and dense-graded airfield (DGA) HMA mix are the two mix types evaluated. These mixes are known to provide high shear and rutting resistance. The research includes development and field experiments to determine the most suitable of these mix types to produce an airfield-quality HMA mix, particularly as an ADR material.

2.3. Scope

AFRL designed two pelletized asphalt candidate mixes (SMA and DGA) for optimal asphalt and voids content and evaluated the mixes using both laboratory as well as field tests. Laboratory and field experiments were conducted on the HMA mixes produced using both pelletized asphalt binder and conventional asphalt binder (to serve as control HMA mix). Laboratory tests for workability and rutting potential were conducted to help select one HMA mix for full-scale accelerated field trials to evaluate field performance of the selected mix type under simulated aircraft traffic. This report documents the experiments, testing and evaluation of pelletized asphalt technology, both in the laboratory and in the field, as an alternative ADR material.

3. LITERATURE REVIEW

3.1. Asphalt Binders

The importance of asphalt binder properties on asphalt-aggregate mixture or HMA performance has long been recognized [(1)]. During the Strategic Highway Research Program (SHRP), significant gains were realized in the characterization of asphalt binders for properties related to performance. Determination of the viscoelastic and low temperature fracture properties of asphalt binders were found to correlate to HMA mixture properties. Today, new fundamental tests are used to characterize and specify asphalt binder which take into account its viscoelastic and thermoplastic nature that is time and temperature dependent. Asphalt binders are directly measured to determine the complex modulus (stiffness) properties over a range of temperatures at a load frequency representative of slow-moving traffic (10 rad/sec) [(2)]. Several binder properties were identified during SHRP research that linked to mixture performance. Low temperature stiffness and strain properties were found to strongly correlate with thermal cracking in field studies. Correlations with fatigue life, stiffness, and dissipated energy of HMA mixes were found for complex modulus properties (G^*, and δ). The phase angle, δ, is a measure of the degree of viscoelasticity of the binder.

$$G^* = \sqrt{(G')^2 + (G'')^2} \tag{1}$$

As shown in Equation 1, the complex modulus G^* consists of two components: (a) storage modulus G' is the elastic, recoverable portion and (b) loss modulus G'' is the viscous or the non-recoverable portion. The inclusion of the phase angle term, $\sin \delta$, is important for modified binders, which often cause significant changes in phase angle without large changes in G^* [(3, 4, 5)]. Figure 1 shows the relationship in Equation 1 in graphic form for two different asphalt binders to demonstrate the importance of phase angle, δ.

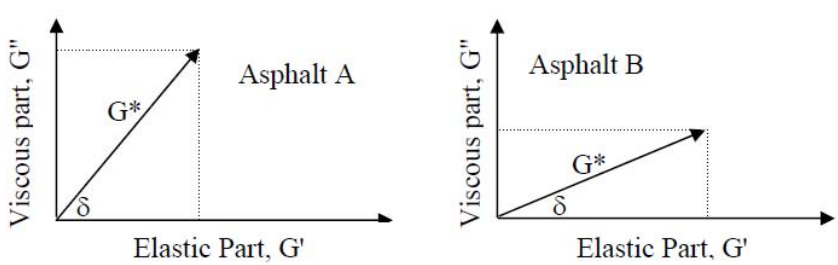

Figure 1. Components of Complex Modulus, G* [(6)]

Both asphalt binders in Figure 1 have the same complex modulus G^*, indicated by the length of the diagonal, but with different phase angles δ. However, asphalt binder B has a larger elastic component compared to asphalt binder A. When both asphalt binders are loaded, asphalt binder B will display more elastic, recoverable deformation and less viscous or non-recoverable, permanent deformation compared to asphalt binder A. This example demonstrates that the complex modulus G* alone is not sufficient to characterize asphalt binders; phase angle δ is also needed [6].

The correlation of binder complex modulus properties with permanent deformation of HMA mixes is weak reflecting the influence of aggregate properties. However, a consensus has developed for a specification to reject binders that have low stiffness. Experiments revealed that in HMA mixes with poor aggregate interlock, complex modulus properties of the binder were important in resisting permanent deformation. The parameter G*/sin δ was selected because it includes modulus and phase angle. This allows the rejection of binders that have low modulus and/or a large viscous component of the complex modulus. Both the tank (original) and Rolling Thin-Film Oven (RTFO)-conditioned materials are tested to reject those binders that may result in tender HMA mixes. The RTFO simulates the short-term aging of the HMA mix from heating, mixing, and storage prior to compaction in the field [3, 4, 5].

3.1.1. SHRP Performance Grading (PG) System

The SHRP specification criteria [3] have been established by comparison of laboratory and field performance data for highways. The SHRP PG system classifies asphalt binders according to the temperatures at which certain performance-related properties are met [3]. The specifications are built around viscoelastic properties such as complex modulus, G*, phase angle, δ, low temperature stiffness, S, and creep rate, m. The criteria for G*/sin δ (the SHRP rutting parameter) are designed to ensure a minimum stiffness of the binder immediately after placement to avoid "tender" mixtures and those mixtures with rutting potential early in the pavement life based on an estimated high pavement temperature. The Superpave binder specifications assume that rutting or permanent deformation is influenced by the accumulation of the nonrecoverable component of the binder response. Thus the specification requires that the dynamic shear rheometer (DSR) performance parameter (G*/sin δ) have a minimum value of 2.20 kPa for aged binders after RTFO aging. A high G* and low δ is desirable in terms of resistance to rutting because the binder will dissipate less energy as permanent deformation per load cycle [7]. The high pavement temperature is determined from the mean 7-day high air temperatures. The maximum for G* sin δ (the SHRP fatigue parameter) helps to identify binders that may be susceptible to fatigue damage as well as those exhibiting excessive embrittlement with age [2, 3].

The SHRP thermal cracking parameters (S and m) are designed to identify binders having poor thermal properties at the low temperatures for a given geographic region. The original SHRP specification required that the low air temperature was equivalent to the low pavement temperature. This was realized to be overly conservative and recent changes to the temperature criterion use the following equation to determine the low air temperature for the specification [8,9, 10].

$$T_{\min} = 0.859 T_{air} + 1.7^{o} C \tag{2}$$

Temperature data specification of a binder for a particular region in North America can be obtained from local weather stations or an extensive database compiled by the Federal Highway Administration (FHWA). This database contains information from thousands of locations in the US and Canada and is available in the SHRPBIND 3.1 software. The software calculates the 7-day mean maximum pavement temperatures and uses the mean lowest air temperatures to determine the SHRP performance grading (PG) for the area selected. The software does not contain the low temperature modification in Equation 2. The SHRPBIND program along with the reliability for the given area calculates SHRP PG's. For geographic areas outside North America, pavement temperatures can be calculated based on local temperatures and conditions [(4)].

For example, a PG76-22 binder refers to a material with the following properties:
1) a minimum flash point of 230°C,
2) a maximum rotational viscosity of 3 Pa sec at 135°C,
3) a minimum of 1000 and 2200 Pa for G*/sin δ for the original (tank) and RTFO test-conditioned materials, respectively, at a 10 radian/sec oscillatory shear and 76°C,
4) a maximum of 5 MPa for G* sin δ for the PAV-aged (Pressure Aging Vessel) material at 10 radian/sec oscillatory shear and 31°C, and
5) a maximum stiffness of 300 MPa and a minimum creep slope of 0.3 at -12°C for the PAV-aged material.

This binder would be suitable in areas with a maximum pavement temperature of 76°C and a minimum air temperature of -27.6°C (calculated using Equation 2) [(11)].

3.1.2. SHRP Tests
The SHRP PG system requires testing by Brookfield viscometer [(11)], dynamic shear rheometer [(8)] and bending beam rheometer [(11).]

3.1.2.1. Brookfield or Rotational Viscometer
Broookfield or rotational viscometer (RV) test is conducted to determine high temperature viscosities of the binder. The test is conducted at 135°C (275°F), to simulate binder workability at mixing and laydown temperatures. AASHTO TP 48 and ASTM D 4402 tests provide instructions to perform rotational viscometer test. The test is conducted by submerging a cylindrical spindle in an asphalt binder sample at a constant temperature. The torque required to maintain a constant rotational speed of 20 RPM is measured and converted to a viscosity. Since the goal is to ensure the asphalt binder is sufficiently fluid for pumping and mixing, Superpave specifies a maximum RV viscosity.

3.1.2.2. Dynamic Shear Rheometer (DSR)
The DSR characterizes the viscoelastic behavior of the asphalt binder at high and intermediate service temperatures. The DSR quantifies the shear complex modulus G*, and the phase angle δ, measured at the desired temperature and frequency of loading. The complex modulus G* represents the total resistance of the binder to deformation when repeatedly sheared.

AASHTO TP5-93 and ASTM Standard D 7175-08 [(12)] provide instructions to perform the DSR test. The test requires a thin asphalt specimen to be sandwiched between two metal plates in a constant temperature bath. One of the two plates then oscillates with respect to the other with specific angular frequency. The material response to the cyclic stresses is then measured by the DSR, and the shear complex modulus G* and the phase angle δ are calculated.

3.1.2.3. Bending Beam Rheometer (BBR)

The BBR evaluates the stiffness of the binder at low temperatures. Thermal cracking of asphalt pavements is caused by the shrinkage induced stresses when air temperatures drop rapidly. During rapid contraction, the stresses accumulate and may eventually exceed the stress relaxation threshold of the material. The limiting stiffness temperature is defined as the pavement service temperature at which a certain stiffness value is reached after a specified loading time [(13)]. AASHTO TP1-93 and ASTM Standard D 6648-08 [(14)] provide the instructions for the BBR test where a PAV-aged asphalt beam specimen is subjected to constant load applied for a set amount of time. The beam-shaped asphalt specimen is maintained at a constant temperature within an enclosed chamber. The beam is supported at the ends and centrally loaded. This test allows collecting data about specimen deflections, load, and time that are subsequently employed in the evaluation of the creep stiffness and the creep rate.

3.2. Aggregate Properties

Aggregates for HMA are usually classified by size as coarse aggregates, fine aggregates, or mineral fillers. ASTM defines coarse aggregate as particles retained on the 4.75-mm (No. 4) sieve, fine aggregate as that passing the 4.75-mm sieve, and mineral filler as material with at least 70 percent passing the 75-μm (No. 200) sieve. Some agencies, such as the Asphalt Institute (AI), may use the 2.36-mm (No. 8) sieve or 2.00-mm (No. 10) sieve as the dividing line between coarse and fine aggregates.
Aggregates for HMA are generally required to be hard, tough, strong, durable (sound), properly graded, and to have clean cut hydrophobic surfaces. Their selection is based on numerous factors such as climate, moisture sensitivity, availability, cost, experience, etc. Aggregates for high quality airfield pavements need to be strong, angular, and durable. The gradation selected must leave adequate void space for the asphalt binder to properly coat the particle while achieving a proper aggregate skeleton to resist deformation. The SHRP designates two types of properties for aggregates, consensus and agency source. Consensus properties are those that are deemed necessary for specification properties and have been arrived at by consensus within the aggregate community. The SHRP consensus properties are aggregate gradation, coarse and fine aggregate angularity, clay content, and thin or elongated particles. Agency source properties are specified by the users and usually include toughness, soundness and deleterious materials.

3.2.1. Aggregate Gradation

The gradation of a particular aggregate is determined by a sieve analysis in which a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings. Once separated, the weight of particles retained on each sieve is measured and compared to the total sample weight. Particle size distribution is then expressed as a percent retained by weight on each sieve size. Gradation has a profound effect on material performance and [11], specifies Superpave aggregate specifications for 37.5 mm down to 9.5 mm nominal aggregate sizes. The appropriate aggregate gradation is achieved by developing a gradation that stays within the control points for a selected nominal aggregate size.

3.2.2. Aggregate Angularity

The angularity of the coarse aggregate is defined by the percentage of aggregate particles larger than 4.75 mm with at least one crushed face. The amount of crushed faces in the aggregate is directly related to the shear strength of the asphalt-aggregate mix and to the ability of the mix to resist permanent deformation. Crushed aggregate faces result in a larger amount of particle to particle contact and interlock and are able to resist applied forces better than rounded aggregates. Fine aggregate is defined as that material passing the 2.36-mm sieve. Fine aggregate angularity is defined as the percent of air voids present in loosely compacted aggregate that passes the 2.36-mm sieve and is determined by the ASTM Method C 1252 *Uncompacted Void Content of Fine Aggregates* [10]. This test is intended to limit the amount of rounded fines, because the more rounded aggregate particles have less void space between adjacent particles than angular aggregates. Angularity requirements are usually based on expected traffic.

3.2.3. Clay Content

Limiting the clay content in aggregate is advantageous for reducing the potential for stripping because of the water-absorptive and expansive characteristics of many clays. Clay content is the measure of the amount of clay material present in the portion of aggregate that passes the 4.75-mm sieve, and is measured by means of the sand equivalent test, AASHTO T176: *Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalency Test*. This test indirectly measures the rate of particle settlement that is related to particle size [3, 10, 15].

3.2.4. Thin and elongated particles

Thin, elongated aggregate particles are defined as those aggregate particles that have a ratio of maximum to minimum dimensions greater than five. These particles have a tendency to break under an applied load which contributes to aggregate segregation and breakdown during compaction. The percentage of these particles is limited to 10 percent by weight of the aggregate proportion as measured by ASTM Standard Method of Test D 4791: *Flat or Elongated Particles in Coarse Aggregate*. This test method requires manual measurements on a random sample of aggregate particles.

3.2.5. Toughness, soundness, and deleterious materials

Aggregate toughness is defined as the resistance to fracture under an impact or applied load as measured by the Los Angeles Abrasion Test[6]. The resistance to fracture under impact or load is measured as percent loss of material from the blended aggregate during the test. Aggregate particles should have sufficient strength to prevent mechanical degradation during sieving, drying, and mixing. Aggregate soundness refers to the ability of the aggregate to withstand weathering cycles such as wetting and drying and freeze-thaw cycling. The method most often employed is AASHTO T104: *Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate*. Deleterious materials are particles of clay, coal, and organic material such as wood, leaves, etc., which may find their way into the aggregate and are measured as the percent by weight of undesirable materials. A suggested value of 2 percent maximum by weight of the aggregate is recommended by the SHRP [10, 15].

3.3. Bituminous Mixture Design

A number of HMA mixture types have been developed in recent years; each mix type has unique properties primarily aimed at improving rut resistance. Since only DGA and SMA were used in this study a brief description of the mixes is described in the following section.

3.3.1. Dense Graded Asphalt Mixtures (DGA)

Dense Graded Asphalt Mixtures are the most common of asphalt mixtures. The aggregate gradation is selected to provide adequate voids for asphalt binder and air in the final compacted mixture. These types of asphalt-aggregate mixtures have a long history of good performance when properly constructed. Two DGA mixture types have been identified for heavy-duty asphalt pavements that must sustain heavy loads and meet strict design life requirements, the SHRP and the US Army Corps of Engineers (COE) DGA mixtures. Although the SHRP designs do not have a proven record of durability, they do have a sound record of resistance to rutting for many projects. The COE designs have been proven over 50 years to provide adequate durability and are extremely resistant to permanent deformations.

The COE's heavy-duty (HD) design is based on the 75-blow Marshall Hammer and utilizes air voids (Va) and voids filled with asphalt (VFA) as criteria for establishing volumetric properties of compacted mixtures. The aggregate gradation must fall within a specific range for the COE HD curves as shown in Figure 2. In addition, requirements for a minimum stability and flow for compacted samples as measured by the Marshall Stability apparatus must be met. Compacted samples are subjected to water damage testing to ensure a minimum resistance level is met. The COE design also requires strict quality control during placement to ensure that the gradation, asphalt content, and density are within the specifications established for a particular job mix formula (JMF) [20].

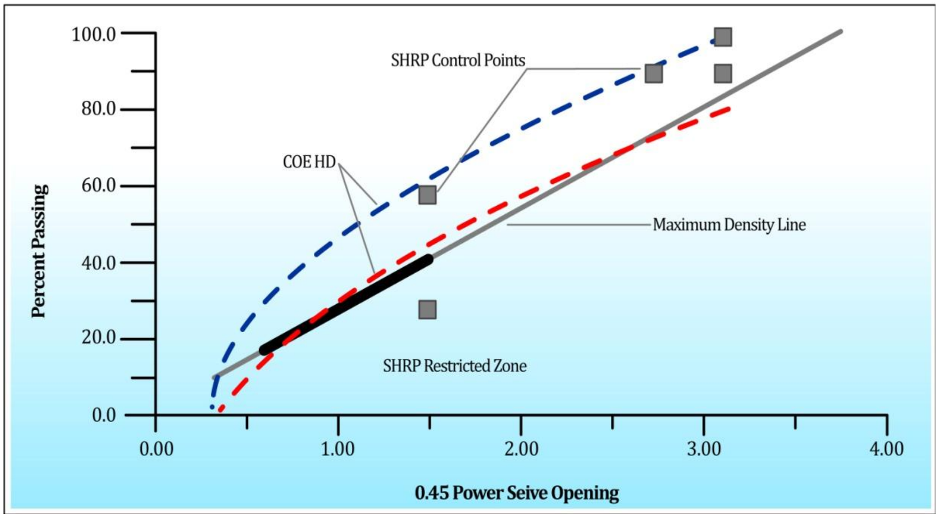

Figure 2. SHRP and COE Sieve Ranges for 19-mm Nominal Aggregate

The SHRP design is based on the SHRP gyratory compactor and utilizes Va, voids in the mineral aggregate (VMA), and VFA as criteria for establishing volumetric properties of compacted mixtures. The aggregate gradation controls established during the SHRP are not as strict as those of the COE. In addition, the SHRP gradation currently requires avoidance of the so-called "restricted zone" which is an attempt to control the amount of natural sand. The aggregate quality is also dependent on the expected traffic level. There is currently some question of the validity of the restricted zone. The SHRP design is focused on the VMA requirements and is intended to achieve durability while allowing for optimum air voids. The SHRP criteria also set requirements on the compaction properties to avoid those that compact too quickly (tenderness). The mixtures must meet stringent criteria for the susceptibility to water damage [3, 10, 15].

3.3.2. Stone Matrix Asphalt

SMA is a HMA design that relies heavily on stone-on-stone contact to resist permanent deformation. The SMA aggregate gradations, based on the National Asphalt Paving Association (NAPA), design is presented in Figure 3 [16]. There are significant differences between typical DGA and SMA gradations. Compared to DGA, SMA has a gap graded coarse gradation with significantly higher VMA. The higher VMA results in higher asphalt binder contents (typically 6-9%) with thicker asphalt films on aggregate particles. This film must be stabilized to prevent the binder from draining from the aggregate surface while hot. Binder stabilization is achieved by the formation of a mastic of asphalt, stabilizer, crushed fine aggregate, and mineral filler. The mastic is usually formed by addition of filler such as cellulose fibers to raise the viscosity and stabilize the flow properties at high temperatures, although stabilization can also be achieved using other means such as polymer modification. The mastic is further stabilized during the mixing with aggregate by using a gradation with relatively large amounts of fines [17].

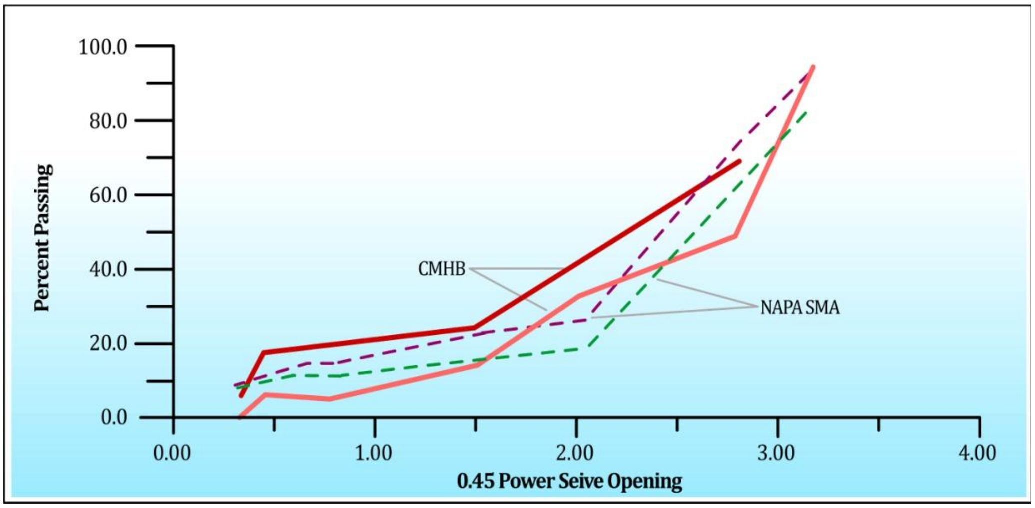

Figure 3. SMA and CMHB Sieve Ranges for 19-mm Nominal Aggregate Size

An essential property in SMA is the stone-on-stone contact that provides the majority of the deformation resistance. Measures of stone-on-stone contact can be obtained by dry-rodding or using the SHRP gyratory compactor [(18)]. Thicker asphalt films on aggregate particles provide increased durability by reducing the ability of water to penetrate the asphalt film and displace the asphalt from the aggregate surface. In addition, thicker asphalt films oxidize slower because of increased diffusion time of oxygen penetrating a thicker film. SMA's also are reported to be less susceptible to thermal cracking because of a higher weight percentage of the viscoelastic component (asphalt binder) that better resists thermal fracture [(19)].

3.4. Binder Transportation and Associated Problems

Convenient transport of asphalt binder is essential as paving sites are generally distant from asphalt binder manufacturers (petroleum refineries). Due to their viscous nature, asphalt binder transport requires specialized containers and precautions. Certain additives are often used to make the binder material relatively more viscous (less flowable); however, these additives pose their own unique problems. For instance, when sulfur is used to stiffen the binder, it has a tendency to separate from asphalt binder, owing to differences in density. The depletion of sulfur in the binder causes the binder to revert back to its original flow properties. Large amounts of sulfur may have a detrimental effect on the quality and performance of the binder. Pelletization technology is a promising alternative that allows for storage and transportation of softer asphalts without adding modifiers.

3.5. Pelletized Asphalt

The binder transportation problem is solved using the pelletized asphalt technology. The pelletized asphalt technology of NiTech Corporation allows asphalt to be converted into a dry mix and stored in the form of small, "pea-shaped" pellets at ambient temperature.

The asphalt pellets are coated with a patented two step process utilizing a polymer emulsion followed by a fine powder, usually a clay. This prevents the asphalt pellets from sticking together.

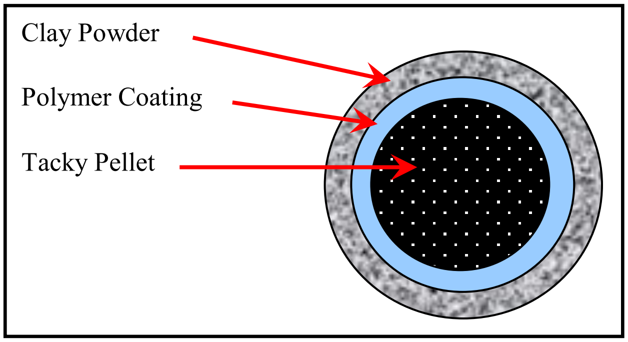

Figure 4. NiTech Pelletized Asphalt

The polymer forms a continuous non-tacky coating, and the polymer and powder are fully compatible with the base material (Figure 4). Coating is precisely controlled, and the typical thickness ranges from 0.6 to 3 mm. The asphalt pellets initially developed had a tendency to interlock due to deformation under pressure owing to their soft nature. NiTech Corporation developed the NiPak technology (patent still pending) to correct this problem. In the NiPak process, a portion of the fines (minus #30 fines) is added to the pellets during the manufacturing process. These fines fill the interstices between the pellets and eliminate the point contact thus creating a uniform hydrostatic pressure around the pellets which minimizes deformation and interlocking of the deformable asphaltic solids. The addition of these fines creates a shippable, storable asphalt pellet product which potentially has a stable shelf life of years at ambient temperatures of up to at least 130°F and which can be poured as a free-flowing material from shipping containers into a continuous or batch mixing plant to produce HMA on demand.

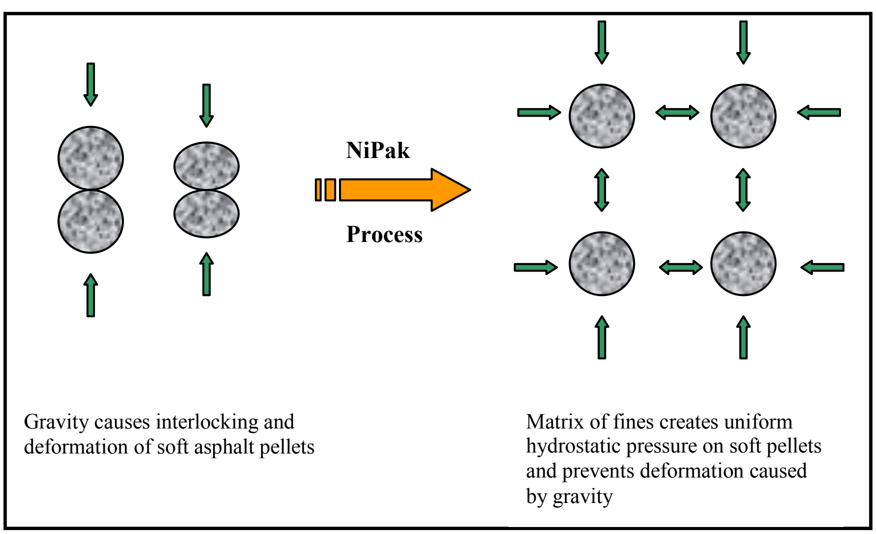

Figure 5. NiPak Technology

Fines are selected as per the HMA mix design and packed with pellets, along with other additives such as fiber, lime, etc. as needed. Aggregate is heated on site with a portable heater/mixer unit until it reaches the desired temperature, and pre-packaged asphalt pellet mix stored at ambient temperature is then introduced to the hot aggregate to produce a DGA or SMA mix.

3.5.1. Advantages of Using Pelletized Asphalt

The adoption of pelletized asphalt has the following advantages for ADR:

- Allows for rapid onsite production to facilitate expedient pavement repair.
- PG grades such as 76-22 can be stored and transported at ambient temperature.
- Can be mixed with locally produced aggregates in a deployable mix plant.
- Testing indicates hot mix from pellets provides equivalent quality of conventional hot mix procured from batch or drum plants.
- Saves energy and costs associated with maintaining asphalt in a molten stage during storage.

4. LABORATORY DESIGN AND EVALUATION OF HMA MIXTURE DESIGN

AFRL developed the HMA mix designs in cooperation with the National Center for Asphalt Technology (NCAT) at Auburn University. The mix design requirements included sufficient mix workability during construction and satisfactory performance when subjected to aircraft traffic.

4.1. HMA Mixture Design

The HMA mix designs were performed in accordance with Unified Facilities Guide Specifications (UFGS) currently approved by the United States Air Force; UFGS 32 13 15 (20) and UFGS 32 13 17 (21) provide guidelines for DGA and SMA mixes, respectively.

Phase I included the design of four HMA mixtures (two DGA and two SMA mixes) using the 50-blow Marshall Design method (ASTM D 6926 – 04 [22]). These mixtures were subsequently analyzed in terms of volumetric properties and performance indicators. One of the DGA mixtures was prepared using conventional asphalt meeting the requirements of performance grade (PG) 76-22 polymer modified asphalt binder and one DGA mix was prepared using PG76-22 pelletized polymer modified asphalt binder; SMA mixes were prepared similarly. Crushed limestone was used during laboratory experiments because of its availability for the Tyndall AFB field testing. Table 1 includes the aggregate gradation employed for the mixtures.

Table 1. Selected Mixture Gradations and Specification Limits

Sieve size	DGA mixture	UFGS range	SMA mixture	UFGS range
19 mm	100	100	100	100
12.5 mm	94	76-96	90	90-100
9.5 mm	87	69-89	78	50-85
#4	65	53-73	36	20-40
#8	50	38-60	22	16-28
#16	32	26-48	16	-
#30	22	18-38	14	-
#50	13	11-2.7	12	-
#100	7	6-18	10	-
#200	4.7	3-6	9.1	8-11

DGA and SMA specimens with pelletized asphalt and conventional asphalt were fabricated and checked for volumetric properties. Table 2 and Table 3 show the characteristics of the mixtures; their volumetric parameters were within the UFGS tolerance limits (20, 21). The target design air voids were 4 percent and 3.5 percent for the DGA and SMA mixtures, respectively. Marshal stability and flow measurements were not performed because they are not required by the UFGS for SMA mixtures.

Table 2. DGA Mixture Characteristics and Specification Limits

Parameters	Conventional PG76-22	Pelletized PG76-22	UFGS range
Optimum Pb (%)	5.0	5.6	-
Va	4.0	4.0	3 - 5
VMA	14.9	15.9	>14
VFA	81.6	73.5	-
Stability (lb)	*	4450	>1350
Flow (0.01in)	N/A	15.0	8-18

* Samples discarded before testing

Table 3. SMA Mixture Characteristics and Specification Limits

Parameters	Conventional PG76-22	Pelletized PG76-22	UFGS range
Optimum Pb (%)	5.8	6.3	-
Va	3.5	3.5	3-4
VMA	17.2	17.8	>17
VFA	86.8	75.8	-

4.2. Workability Tests

Additional testing evaluated the workability of these mixtures in order to estimate their field compactibility. HMA mix gradation, binder type and content, additives, and temperature influence its workability. An NCAT test apparatus was selected to estimate HMA workability. This device consists of a paddle system pushed by a rotor fitted with a torque transducer. A simple data acquisition system records the torque required to maintain a given revolution rate at 120°C [(23)].

Figure 6 shows results of workability tests on HMA mixes prepared using conventional asphalt binder; DGA samples were relatively more workable (characterized by lower torque) than SMA samples. Data plotted shows torque required at 120°C and 140°C for both DGA and SMA samples. Appendix A provides plots of workability tests on DGA and SMA samples for conventional and pelletized asphalt mixes. In conclusion, the DGA mixture required less energy to work at both temperatures of 120°C and 140°C than SMA mixture. Therefore, it allows for relatively better compaction of the material (at the same compaction effort) when placed in the field.

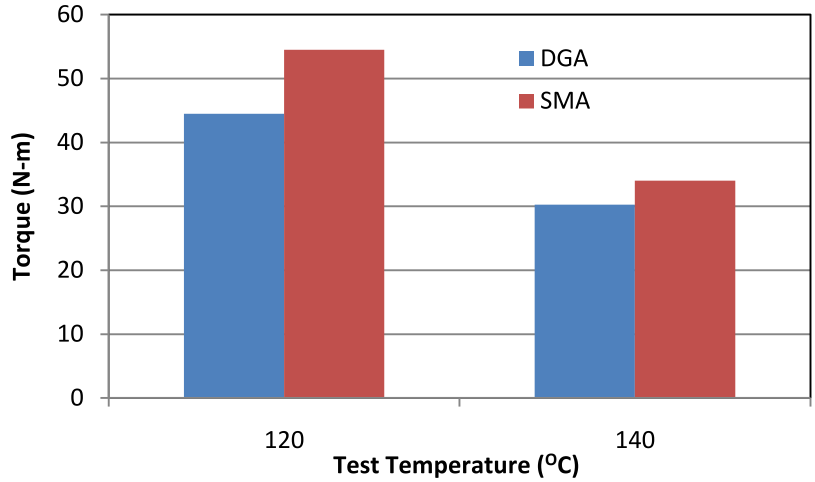

Figure 6. Workability Measurements of the Mixtures

4.3. Susceptibility to Permanent Deformation

Samples were tested with the Asphalt Pavement Analyzer (APA) to evaluate rutting susceptibility, based on the AASHTO T 63 [(24)], to evaluate mixture performance in terms of permanent deformation. In this test an HMA sample is subjected to repetitive wheel loads and the amount of permanent deformation under the wheel path is measured (Figure 7). The wheel loads and contact pressure are adjusted to represent actual field conditions.

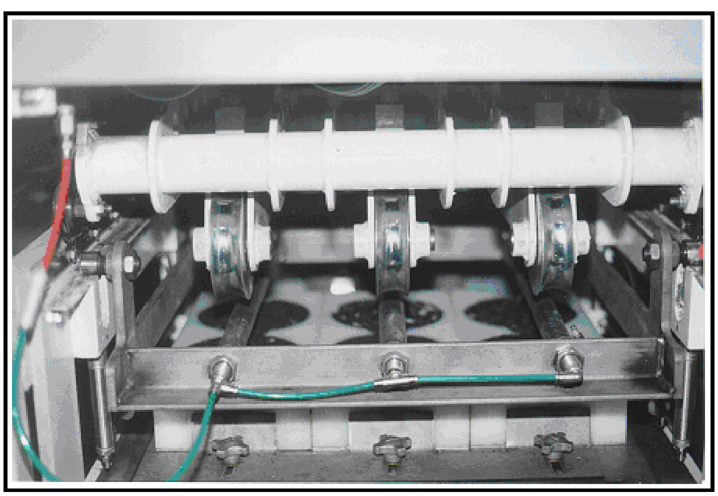

Figure 7. The APA for Evaluating the Rutting Susceptibility of HMA Mixes

Both asphalt mixtures were tested using load levels of 445 N and 1070 N; the latter is basically the highest load the APA can accommodate. Under the 100-lbs wheel load, the DGA specimens showed good rutting performance with an average rut depth of 2.8 mm.

In particular, the DGA mixture using pelletized asphalt had a rut depth of 2.6 mm compared to 3.0 mm for the regular PG76-22. The APA results for the SMA mixtures were higher with an average rut depth of 4.0 mm. When the mixture with asphalt pellets were tested under the 1070-N wheel load, the DGA performed again better than the SMA. The rutting measured for the DGA mixture with pelletized asphalt was 4.3 mm, whereas the SMA had an average rut depth of 5.8 mm. Table 4 summarizes the results of the APA rutting tests.

Table 4. Rutting Measurements From the APA Tests

Test parameters	445 N wheel load; 0.69 MPa hose pressure		1070-N wheel load; 0.83 MPa hose pressure	
Binder type	Conventional PG76-22	Pelletized PG76-22	Conventional PG76-22	Pelletized PG76-22
DGA mixture	3.0 mm	2.6 mm	N/A	4.3 mm
SMA mixture	4.3 mm	3.7 mm	N/A	5.8 mm

The laboratory results from the workability and rutting tests led to the selection of the DGA mixture for field trials. The DGA mixture is also a more economical design than the SMA mix design due to its lower binder content, less restrictive aggregate requirements, and the absence of stabilizing fibers as required in SMA. Thus, the DGA mixture was employed for the field testing at Tyndall AFB, FL.

5. CONSTRUCTION AND EVALUATION OF ON-SITE TEST SECTIONS

Based on laboratory testing results, DGA mix was selected for field evaluation of HMA mix with pelletized asphalt. The field evaluation helped determine the feasibility of producing pelletized HMA using a standard asphalt plant, ease of placement, and its performance under simulated aircraft traffic using the F-15 load cart.

5.1. Construction of Test Sections

The selected DGA mixture was employed for the field testing at Tyndall AFB, FL. Two test sections (7.6 m by 15.2 m) were built on the existing concrete runway at the Silver Flag training field. Construction was done on May 13 and 14, 2008. Gulf Asphalt Contractor (GAC), Panama City, FL, provided all labor, material (with the exception of pelletized asphalt) and equipment for test section construction. One section was built with DGA mixture with conventional binder; the other was prepared with pelletized asphalt mixture. The HMA mix was manufactured at a nearby batch plant and transported using standard end dump trucks.

5.1.1. HMA Placement and Compaction

A mechanical sweeper swept clean the existing concrete surface as shown in Figure 8A. Soil, concrete and other debris were removed and the existing pavement was prepared for application of a tack coat. Figure 8B shows a distributor vehicle spraying liquid asphalt tack coat on the area marked for construction of test sections. Tack coat was applied to the existing concrete surface to ensure that there was adequate bonding between the asphalt overlay and the concrete surface. Inadequate bonding results in delamination/debonding of the top layer and may cause excessive cracking or permanent deformation of the asphalt layers, once traffic loads are applied.

HMA was placed using an automated paver as shown in Figure 8C. The 100-mm thick test sections were constructed in two lifts each approximately 50 mm thick. This allowed for proper leveling and compaction of the placed material. After placing the first lift, it was compacted using a steel wheel roller as shown in Figure 8D. The second lift was placed after adequate compaction was carried out by the steel wheel roller (Figure 8E). After placement of the second lift, the surface was again compacted with steel wheel roller and finally finished using a pneumatic tire roller (Figure 8F).

Figure 8. HMA Test Section Construction Used Conventional Paving Equipment

5.2. HMA Mixture Evaluation

During construction, NCAT sampled and tested pelletized and conventional HMA for quality control (QC) purposes. Table 5 summarizes the target job-mix formula (JMF) of the mixes employed for test sections construction.

Table 5. Job-Mix Formula for the Pelletized HMA Test Section

<table>
<tr><th>Sieve size</th><th>DGA</th><th>Asphalt content</th></tr>
<tr><td>19 mm</td><td>100</td><td rowspan="5">Mixture with pelletized asphalt
Optimum Pb = 5.6 %</td></tr>
<tr><td>12.5 mm</td><td>94</td></tr>
<tr><td>9.5 mm</td><td>87</td></tr>
<tr><td>#4</td><td>65</td></tr>
<tr><td>#8</td><td>50</td></tr>
<tr><td>#16</td><td>32</td><td rowspan="5">Mixture with conventional asphalt binder
Optimum Pb = 5.0 %</td></tr>
<tr><td>#30</td><td>22</td></tr>
<tr><td>#50</td><td>13</td></tr>
<tr><td>#100</td><td>7.4</td></tr>
<tr><td>#200</td><td>4.7</td></tr>
</table>

GAC Contractors made available their laboratory for material testing at the production plant. Additional material was retrieved from the plant for binder testing at the NCAT. On site, the sampled mixture was tested for gradation and asphalt content; Table 6 includes sieve analysis results and the acceptance limit included in the UFGS 32 12 15.

Table 6. Pelletized HMA Sieve Analysis Results Vis-à-vis UFGC Criteria

Sieve size	Percent Passing	UFGS 32 12 15 Acceptance limits
19 mm	100.0	92-100
12.5 mm	97	68-100
9.5 mm	92	61-97
#4	68	45-81
#8	516	32-66
#16	35	20-54
#30	26	12-44
#50	20	5-33
#100	16	4-20
#200	12.8	1-8

The percentage passing the #200 sieve was outside the specifications acceptance range due to difficulty handling asphalt pellets during production before the JMF had been finalized. As previously described, the asphalt pellets are suspended (packed) within a matrix of fine aggregates that prevents conglomeration of the pellets during shipment and storage. However, the fines matrix used for shipment of the pellets for this demonstration project was different from that indicated by JMF; therefore, the fines matrix in the pellet containers had to be removed prior to adding the pellets to the HMA production plant. Some of those fines from the shipment of pellets were not completely removed affecting the HMA gradation. The percent passing the #200 sieve was higher than permitted by the UFGS specification.

The bulk and maximum theoretical specific gravity (Gmb and Gmm) were 2.401 and 2.590, respectively. The Va content was 7.3 percentage, and the asphalt content determined using the ignition oven, in accordance with AASHTO T 308 [25], was 5.48 percent.

The construction of each test section required two truckloads of HMA. Temperatures of both conventional and pelletized asphalt mixtures were taken at the plant before delivery and at HMA placement. The first pelletized HMA truck had a temperature of 188°F on the surface and 300°F in the mass center of the HMA. The temperature values for conventional asphalt HMA before delivery were 195°F on the surface and 260°F in the mass center. The temperature of the pelletized asphalt HMA in the second truck load was even higher and was 226°F on the surface and 397°F in the mass center; it was overheated. The high temperatures were caused by an increase of the aggregate drying duration before mixing it with the asphalt pellets. The plant temperature was set to 350°F and then increased to 400-410°F by GAC Contractors to assure complete drying of slightly wet coarse aggregate and melting and mixing of the pelletized asphalt with the aggregate material. This correction produced an overheated material, potentially damaging (over-oxidizing) the pelletized asphalt binder (impacting long-term durability).

5.3. Binder Testing for Aging (Oxidation)

A series of tests were performed on the extracted binder from pelletized HMA samples through the Rotary Evaporator (Rotovap) process (ASTM D 5404 [26]) to evaluate if any changes in binder characteristics occurred during mixture production. These binder tests included the PAV, the DSR, and the BBR each described in Section 0.

The temperature-related viscoelastic behavior of the binder influences the pavement performance in terms of rutting and fatigue cracking. Although rutting is mainly caused by construction practices (compaction), asphalt mix design, and aggregate characteristics, the binder is also a factor to consider. Rutting is more likely to occur at high service temperatures that increase the fluidity of the asphalt binder (reducing viscosity). With time, the contribution to rutting of the binder tends to decrease because of the age hardening of the binder material. On the other hand, excessive asphalt binder hardening may significantly decrease the fatigue resistance of the pavement facilitating the generation of fatigue or alligator cracking [28].

The tested binder was extracted from pelletized asphalt mixture samples from the first and second truck load and from the mixture produced using a deployable HMA plant. The latter mixture was delivered directly to the NCAT facility from the deployable HMA plant evaluation site.

The original and recovered binders were graded according to the guidelines contained in the ASTM D 6373-07e1 [29]. The asphalt binder from the pellets was tested before and after the aging process through the RTFO (ASTM D 2872-04 [30]). This procedure simulates the binder aging during the HMA production and construction of the pavement and quantifies the loss of volatiles which indicates the amount of aging induced in the material. Tables B-1 to B-5 in Appendix B include the NCAT laboratory test reports with the binder grading summaries. Table 7 summarizes the critical temperature values inferred from the analysis of the test results.

Table 7. Extracted Binder Critical Temperatures Indicating Binder Aging

Criteria	Pellets not-RTFO aged	Pellets RTFO aged	Truck #1	Truck #2	Deployable plant
1. DSR RTFO					
T_{max} for $G^*/\sin\delta$ = 2.20 kPa	76.9	85.4	88.8	101.8	96.0
2. DSR PAV					
T_{int} for $G^*\sin\delta$ = 5,000 kPa	23.0	24.7	25.4	29.0	27.6
3. BBR PAV					
T_{min} for S(t) = 300 MPa	-29.2	-24.8	-24.6	-38.2	-23.2
T_{min} for m = 0.300	-28.9	-24.1	-23.9	-19.2	-22.7

The analysis of data reported in Table 7 shows change in binder performance grade (PG) occurring during the production of the mixture. Table B-1 andTable B-2 shows the variation in PG when the binder is worked in the asphalt plant. In particular, Table B-2 illustrates the simulated aging through the RTFO process. These results and the consequent difference in grading of the binder prior and post mixture production are commonly observed in conventional asphalt binders. However, the outcomes were also confirmed by the tests on the mixture sampled from the first truck load (truck #1), as shown in Table B-3.

The test results on the material from the second truck load (truck #2) reported on Table B-4 confirmed the effect that overheating had on the binder characteristics. Overheating drastically changed the PG grade of the binder that originally PG76-22. Moreover, the mixture overheating was clearly observed on the field during the load and delivery of the mixture. The binder showed higher values of the maximum and intermediate temperatures suggesting more susceptibility to fatigue cracking during service life.

Table B-5 illustrates the PG rating of the binder extracted from the mixture when produced by the deployable HMA plant. The end results presented a binder that was subjected to excessive aging; in fact, the PG grade changed from the theoretical PG76-22 to PG94-22. During production, the mixture may have been slightly overheated; however, no overheating was observed during initial evaluation of the deployable HMA plant.

The higher values of the intermediate temperatures (Table 7) suggested that the binders from the second truck load and the deployable mixer were more brittle and had more susceptibility to fatigue cracking. In contrast, the intermediate temperatures evaluated for the binders from the pellets (before and after aging) and truck load #1 were within the range of acceptable values, therefore no change of binder performance is expected. Similarly, the lower temperatures were affected by the overheating during production. The binders from the first truck load and the pellets were within acceptable values. However, the binder of the second truck load and the mobile device were clearly affected by overheating that rendered it more vulnerable to thermal cracking limiting its performance at lower temperatures.

5.4. Field Testing for Permanent Deformation

Field tests helped determine permanent deformation susceptibility of the pelletized vis-à-vis conventional asphalt HMA. Both test sections were trafficked with 1500 passes of AFRL's F-15E load cart (Figure 9), using a channelized trafficking pattern. The tire inflation pressure during the test was 2.17 MPa and the single tire carried a load of 157 kN. Five lanes spaced 0.3 m apart were marked (Figure 10 and Figure 11) for trafficking using the F-15E load cart. Traffic was applied by driving the load cart forward and backward over the length of the test section and then shifting the path of the load cart laterally to move on to the next marked lane. Loading was normally distributed across 1.22-m wander width in the 5 lanes which were spaced at 0.3 m center to center. Trafficking was continued to 1500 passes or failure, whichever occurred first. Failure was defined as permanent deformation of 25 mm or greater.

Figure 9. F-15E Load Cart

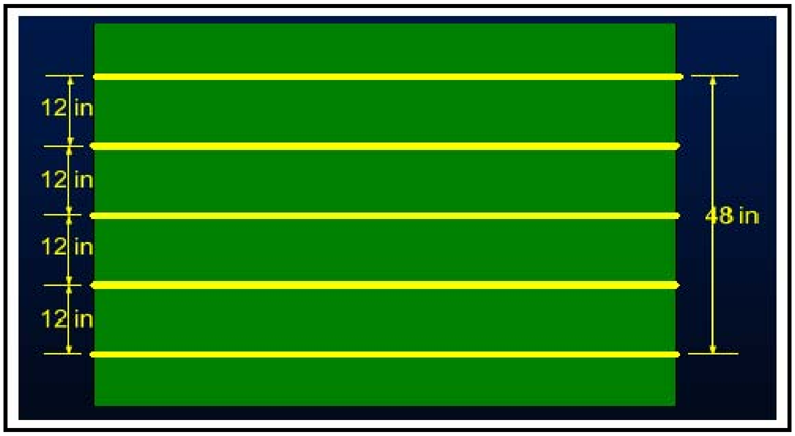

Figure 10. Traffic Pattern for F-15E Load Cart

Figure 11. Test Pad Trafficking Pattern Marked on the Test Section

Figure 12 shows elevation surveys made using a rod and level to measure the transverse profile (permanent deformation) of the pavement. Measurements were taken at 76-mm intervals for a distance of 0.76 m on either side of the centerline of the wheel path, at five transverse intervals (1.5, 3, 4.5, 6, and 7.5 m) along the length of the test section. Also, a straightedge was used to measure maximum permanent deformation at the same transverse intervals (Figure 13). Measurements were made after completing 10, 16, 32, 48, 80, 112, 160, 256, 512, 752, 1008, 1248, and 1504 passes with the load cart.

Figure 12. Elevation Measurements Using Rod and Level

Figure 13. Straight Edge Used to Measure Rutting of the Test Sections

Figure 14 shows the permanent deformation measurements after 0, 512, 752, 1008, 1248 and 1504 passes of F-15E load cart. No permanent deformation was observed in the pelletized asphalt; whereas, the conventional asphalt showed considerable deformation. The maximum deformation observed in conventional asphalt after 1504 passes was 22.5 mm, 2.5 mm short of the defined failure criteria. However, straightedge measurements showed rutting in excess of 25 mm in the conventional asphalt section after 1504 passes.

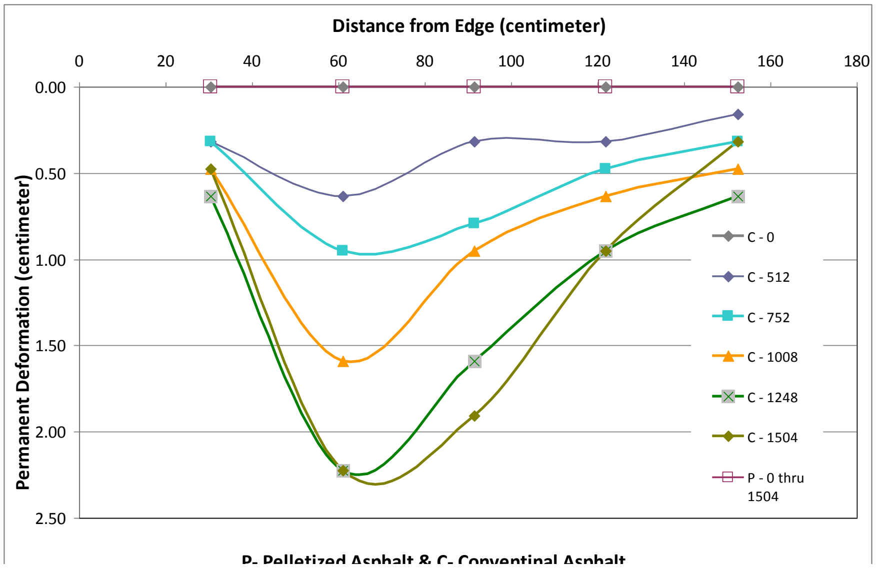

Figure 14. Permanent Deformation Versus Number of F-15E Load Cycles

6. SPECIAL CONSTRUCTION CONSIDERATIONS

The feasibility of using a mobile plant for mixture production was part of the original project developed by AFRL. Section 6.1 provides a brief description of a deployable HMA plant which was leased from Pavement Technologies International Corporation (PTIC), www.PavementGroup.com, for initial evaluations before committing to purchasing a larger unit for AFRL's use.

6.1. Deployable HMA Plant

The deployable HMA plant, as shown in Figure 15, is manufactured by Recycling Solutions Limited (RSL) of United Kingdom represented by PTIC in the United States. The plant produces virgin HMA and has the capability to recycle asphalt millings on site with a production rate of about 15 to 20 tons per hour. It also has the ability to output as little, perhaps one-wheel-barrow-load, or as much as a full 5 ton batch at one time. Its characteristics include the possibility to add bitumen, other additives, or dry aggregates without the risk of overheating the binder already in the drum. The simplicity and safety of the functions makes it ideal for potential field operations. The following section describes the deployable HMA plant in greater detail.

Figure 15. Mobile HMA Plant

6.1.1. PT 5000 - Recycler & Mix Plant

PT 5000 is a deployable HMA mix plant designed to produce virgin HMA, high-performance cold patch and specialty asphalt products as well as to recycle asphalt millings and large asphalt chunks up to 0.6 m by 0.6 m in size.

Loading Machine: The hopper atop the deployable HMA plant holds up to 0.9 metric ton of material and can be loaded with a bucket loader or other appropriate means as shown in Figure 16. Loading hoppers can be customized to accommodate individual loading bucket size and configured for either side or rear loading. An optional side-load bin is available to accommodate material loading at ground level. Load and unload conveyors can also be attached as necessary. It generally takes 4 to 5 minutes to load a 4.5 metric ton batch.

Figure 16. Deployable HMA Plant Being Loaded With Supersacks

Drum design: The drum contains 48 lifters, claw-like fingers which lift the aggregate material for optimal drying. The drum rotates on a set of wheels on a track on one end with a large center bearing located around the middle on the other end, outside of the drum. The drum rotates via a gear box and a hydraulic motor at 4 rpm fully loaded; overall drum design is similar to a drum at conventional HMA plants.

Figure 17. Material Lifters Inside the Mixing Drum

Operation & Controls: Curb-side operator controls are simple to use with electronic switches operating hydraulic controls. Figure 18 shows the control panel for the deployable HMA plant. The unit is simple to operate and push- button functions simplify the operation with most of the processes fully automated. A simple hydraulic lever is used to control material discharged from the machine. Other processes such as heating time and temperature are fully automatic and do not require operator intervention.

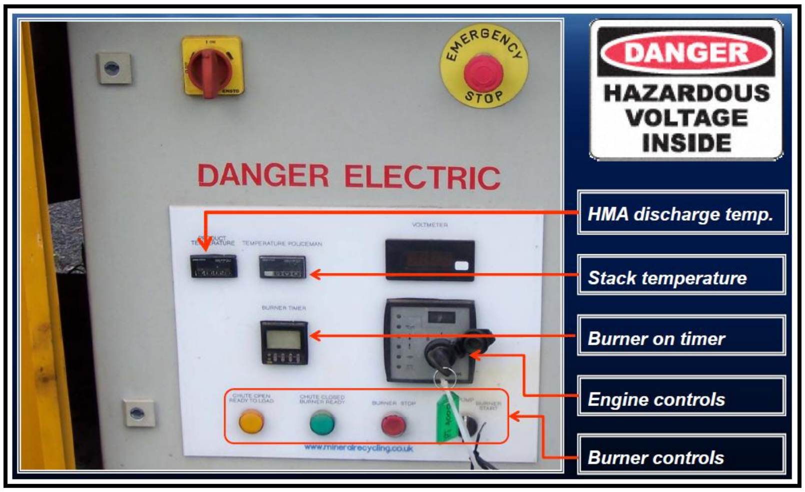

Figure 18. Control Panel for the Mobile HMA Plant

Figure 19. HMA Discharge From the Deployable Plant (Photo – PTIC Website)

Unloading Hot Mix: Material discharges from the rear of the plant, as shown in Figure 19. At discharge, the mixing drum tilts at a maximum angle of about 35 degree. This allows rapid discharge of the entire load. A full 4.5 metric ton load takes 4-5 minutes as the drum is fully raised for emptying. Small quantities, such as a wheel barrow load of hot-mix can be unloaded easily from the intermediary exit hopper, which holds about ¼ metric ton of hot-mix. A hydraulic lever operates the discharge gate allowing a large wheel barrow to be filled in a few seconds.

Dust Control System: A built in air filtration system eliminates the vast majority of airborne dust and smoke, making the unit very environmentally friendly. The filter assembly slides in and out for quick and easy cleanout.

Quiet Operation: The recycler is fully sound-proofed for quiet operation. When the engine enclosure is open, the engine produces sound levels 7 meters of 63db and 85db. This makes it safe for the workers and quiet for the surroundings.

Safety: The unit is designed to prevent accidental overheating of material. If exhaust temperature exceeds a preset target temperature, the burner (Figure 20) shuts off automatically and does not allow a restart until the stack temperature drops below the target temperature. Temperature settings are made tamper-proof and require operators to enter a security code to alter the shut down timer or temperature settings. Safety shut down switches are located on each side of the machine. The machine has anti-burst-out rams on the lift and safety legs that come in and lock in place.

Figure 20. Heat Burner for the Mobile HMA Plant

Cost Effective: The plant uses only 5 liters of diesel fuel per metric ton of HMA produced. Benefits include: reduced transportation, traffic disruption, operating costs, and labor costs, while increased productivity and significant carbon savings.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

1. Pelletized asphalt can be used in conjunction with locally available aggregates to produce an equivalent or higher performance HMA mix then produced using conventional asphalt binder.

2. Between the two mix types evaluated in the laboratory, workability tests indicated that the DGA mixture required less energy than SMA mixture and therefore would allow better lift compaction when placed in the field.

3. APA tests with load levels of 445 N and 1070 N indicated that the DGA performed better than the SMA mixture showing lower average rut depth.

4. The DGA mixture was also found to be more economical than the SMA mixture owing to its lower binder content, less restrictive aggregate requirements, and the absence of stabilizing fibers as required in SMA.

5. DGA mix with pelletized asphalt exhibited better resistance to permanent deformation as compared to DGA mix with conventional asphalt.

6. During construction of the test sections, samples of the asphalt mixture produced with asphalt pellets had the percentage passing the No. 200 sieve outside the acceptance range of the specifications; however, this did not appear to impact field performance results.

7. Temperature results of both standard and pelletized asphalt mixtures indicated that the asphalt pellet mixture was overheated at the plant. This was caused by the plant operator making temperature adjustments to the aggregate prior to mixing it with the asphalt pellets. The damages on the binder were evident during classification of the PG grade extracted from these samples.

8. Test section construction confirmed that it is feasible to manufacture, transport, and place pelletized asphalt HMA using a conventional HMA plant, standard dump trucks, and conventional paving equipment, respectively.

9. Load cart testing indicated that pelletized asphalt section has better resistance to permanent deformation as compared to conventional asphalt test section.

10. The pelletized asphalt test section showed no permanent deformation after 1,504 load applications of F-15E load cart while the conventional asphalt test section showed a deformation of 22.5 mm, 2.5 mm short of the failure criteria.

7.2. Recommendations

1. It is recommended to closely monitor the temperature during HMA production using either the conventional asphalt plant or the deployable HMA mixer to avoid overheating and therefore negatively influencing binder performance.

2. It is recommended to perform future tests on the mixture produced by the deployable HMA plant with additional field demonstrations for a complete evaluation of the asphalt pellets in terms of aging and oxidation. Density and volumetric analysis of field cores is also recommended to assess the compactability of the mixture during field implementation.

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Appendix A: Results of workability tests on mixtures

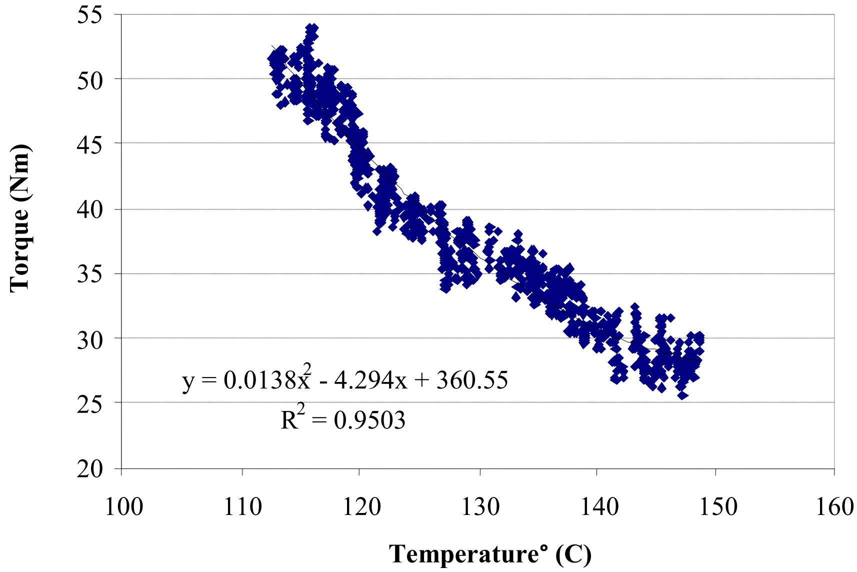

Figure A-1. Workability Chart for Sample #1 of DGA Mixture

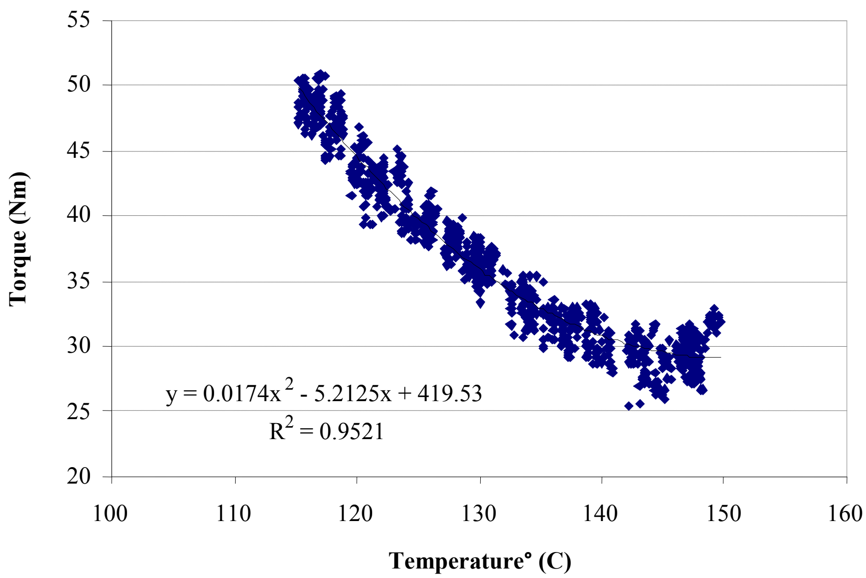

Figure A-2. Workability Chart for Sample #2 of DGA Mixture

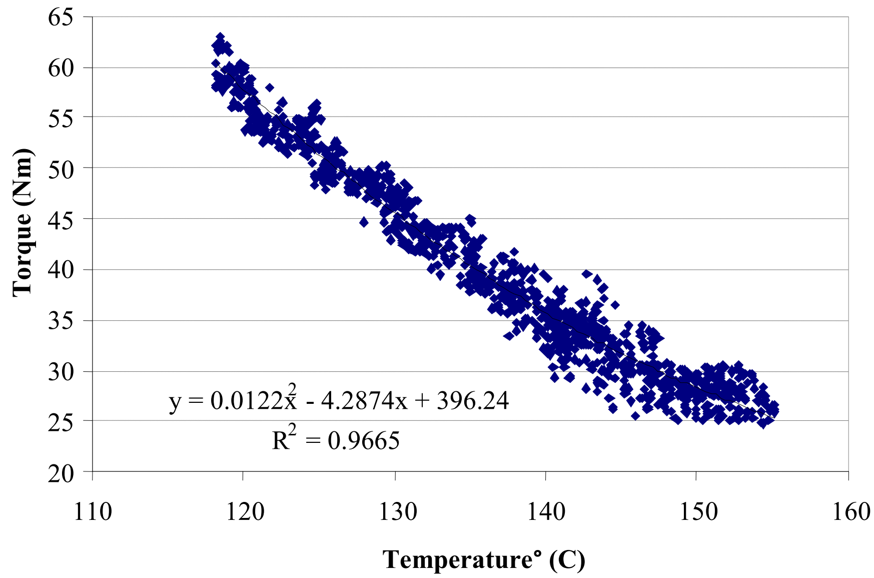

Figure A-3. Workability Chart for Sample #1 of SMA Mixture

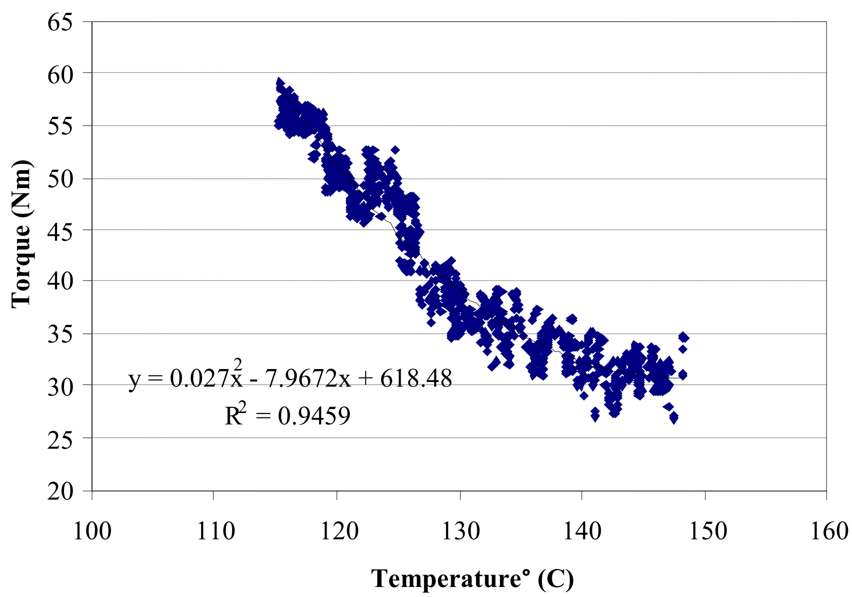

Figure A-4. Workability Chart for Sample #2 of SMA Mixture

Appendix B: Binder Grading Summaries

Table B-1. Laboratory Report on the Binder From the Pellets (Not-RTFO Aged)

National Center for Asphalt Technology				
Superpave Asphalt Binder Grading Summary ASTM D 6373-07e1				
		Sample ID:	Pellets	
Rolling Thin Film Oven (not-RTFO) Aged Binder, ASTM D 2872-04				
Test Method			Test Results	Specification
Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	G* / sinδ, kPa
76	2.25	70.2	2.39	≥ 2.20 kPa
82	1.31	72.3	1.37	
Pressure Aging Vessel (PAV) Aged Binder, ASTM D 6521 Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	G* sinδ, kPa
25	5321	46.4	3854	≤ 5,000 kPa
22	8133	44.1	5657	
Bending Beam Rheometer (BBR) ASTM D 6648-08				
Test Temperature, °C				
-6		Stiffness, MPa	111	≤ 300 MPa
		m-value	0.371	≥ 0.300
-12		Stiffness, MPa	197	
		m-value	0.338	
True Grade	**76.9**	**-28.9**		
PG Grade	**76**	**-28**		

Table B-2. Laboratory Report on the Binder From the Pellets (RTFO Aged)

National Center for Asphalt Technology				
Superpave Asphalt Binder Grading Summary ASTM D 6373-07e1				
		Sample ID:	Pellets (RTFO)	
Rolling Thin Film Oven (RTFO) Aged Binder, ASTM D 2872-04				
Test Method			Test Results	Specification
Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	G* / sinδ, kPa
82	2.77	65.3	3.05	≥ 2.20 kPa
88	1.59	67.2	1.73	
Pressure Aging Vessel (PAV) Aged Binder, ASTM D 6521 Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	G* sinδ, kPa
25	7039	43.6	4850	≤ 5,000 kPa
22	10600	41.3	6988	
Bending Beam Rheometer (BBR) ASTM D 6648-08				
Test Temperature, °C				
-12		Stiffness, MPa	216	≤ 300 MPa
		m-value	0.316	≥ 0.300
-18		Stiffness, MPa	395	
		m-value	0.271	
True Grade	**85.4**	**-24.1**		
PG Grade	**82**	**-22**		

Table B-3. Laboratory Report on the Binder Extracted From Truck Load #1

National Center for Asphalt Technology				
Superpave Asphalt Binder Grading Summary ASTM D 6373-07e1				
		Sample ID:	Truck #1	
Rolling Thin Film Oven (RTFO) Aged Binder, ASTM D 2872-04				
Test Method			Test Results	Specification
Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	G* / sinδ, kPa
82	3.66	64.2	4.06	≥ 2.20 kPa
88	2.16	66.2	2.36	
Pressure Aging Vessel (PAV) Aged Binder, ASTM D 6521 Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	G* sinδ, kPa
25	7613	43.7	5259	≤ 5,000 kPa
28	5167	45.7	3697	
Bending Beam Rheometer (BBR) ASTM D 6648-08				
Test Temperature, °C				
-6		Stiffness, MPa	79.4	≤ 300 MPa
		m-value	0.401	≥ 0.300
-12		Stiffness, MPa	233	
		m-value	0.324	
True Grade	**88.8**	**- 23.9**		
PG Grade	**88**	**-22**		

Table B-4. Laboratory Report on the Binder Extracted From Truck Load #2

National Center for Asphalt Technology				
Superpave Asphalt Binder Grading Summary ASTM D 6373-07e1				
		Sample ID:	Truck #2	
Rolling Thin Film Oven (RTFO) Aged Binder, ASTM D 2872-04				
Test Method			Test Results	Specification
Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	G* / sinδ, kPa
82	9.52	54.9	11.63	≥ 2.20 kPa
88	5.82	55.9	7.02	
Pressure Aging Vessel (PAV) Aged Binder, ASTM D 6521 Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	G* sinδ, kPa
28	8739	39.4	5542	≤ 5,000 kPa
31	6109	41.2	4023	
Bending Beam Rheometer (BBR) ASTM D 6648-08				
Test Temperature, °C				
-6		Stiffness, MPa	87.7	≤ 300 MPa
		m-value	0.369	≥ 0.300
-12		Stiffness, MPa	145	
		m-value	0.238	
True Grade	**101.8**	**- 19.2**		
PG Grade	**100**	**-16**		

Table B-5. Laboratory Report on the Binder Extracted From Mobile Mixer Sample

National Center for Asphalt Technology				
Superpave Asphalt Binder Grading Summary ASTM D 6373-07e1				
		Sample ID:	Mobile Mixer	
Rolling Thin Film Oven (RTFO) Aged Binder, ASTM T 240				
Test Method			Test Results	Specification
Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* / sinδ, kPa	G* / sinδ, kPa
82	6.48	59.9	7.49	≥ 2.20 kPa
88	3.9	61.6	4.43	
Pressure Aging Vessel (PAV) Aged Binder, ASTM D 6521 Dynamic Shear Rheometer ASTM D 7175-08				
Test Temperature, °C	G*, kPa	Phase Angle δ, °	G* sinδ, kPa	G* sinδ, kPa
28	10570	39.3	6701	≤ 5,000 kPa
31	7211	41.5	4779	
Bending Beam Rheometer (BBR) ASTM D 6648-08				
Test Temperature, °C				
-6		Stiffness, MPa	258	≤ 300 MPa
		m-value	0.306	≥ 0.300
-12		Stiffness, MPa	462	
		m-value	0.256	
True Grade	**96**	**-22.7**		
PG Grade	**94**	**-22**		

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AFB	Air Force Base
AFRL	Air Force Research Laboratory
AI	Asphalt Institute
APA	Asphalt Pavement Analyzer
BBR	Bending Beam Rheometer
COE	Corps of Engineers
DGA	Dense-graded airfield
DGA	Dense-graded asphalt
DSR	Dynamic shear rheometer
FHWA	Federal Highway Administration
GAC	Gulf Asphalt Contractor
HMA	Hot-mix asphalt
JMF	Job mix formula
NAPA	National Asphalt Paving Association
NCAT	National Center for Asphalt Technology
PAV-aged	Pressure Aging Vessel
PTIC	Pavement Technologies International Corporation
PG	Performance grading
PCC	Portland cement concrete
QC	Quality control
RSL	Recycling Solutions Limited
Rotovap	Rotary Evaporator
RV	Rotational viscometer
SMA	Stone mastic asphalt
RTFO	Thin-Film Oven
UFGS	Unified Facilities Guide Specifications
VFA	Voids filled with asphalt
VMA	Voids in the mineral aggregate